Influence of Plant Available Water at Seeding on Spring Wheat and Sunflower Production in North Dakota

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Information about plant available water (PAW) at seeding is essential for management decisions concerning fallow or recrop, range carrying capacity, hay production, saline seep control, and participation in farm programs. In the northern Great Plains, growing season precipitation seldom supplies the water needs of a crop, so stored soil water serves as a reservoir from which crops can draw during periods of limited precipitation (Cole and Mathews, 1938; Norum, 1963; Bauer et al., 1965).

Cole and Mathews (1940) established that soil water content, determined by depth of moist soil at seeding, was a good indicator of potential yields. They found low probability of obtaining economic wheat yields when soils were moist to depths less than 12 inches, but average yields more than doubled when moist soil extended beyond 24 inches. The work of Compton (1942) and Janzen et al. (1960) supported these findings in Kansas and Saskatchewan. Depth of moist soil at seeding and soil texture were used by Brown et al. (1981) to estimate PAW and are important variables in the FLEXCROP management system (Halverson and Kresge, 1982). Goos et al. (1984) found low yields and high potential for crop failure in North Dakota if PAW in the rooting zone was less than 3 inches. Enz et al. (1986) stressed the importance of PAW in crop management decisions and annually conduct a survey of soil water on cropped sites across North Dakota.

Several researchers have quantified the relationship between PAW and wheat production. In Montana, Army and Hanson (1960) found correlation coefficients of 0.47 and 0.49 between PAW and yield on recrop and fallow, respectively. On sandy loam, loam, and clay soils in Saskatchewan, Lehane and Staple (1964) reported correlation coefficients between PAW and wheat yields of 0.45 to 0.57. Leggett (1959) reported a correlation coefficient of 0.77 between the same variables in Washington. In North Dakota, Young et al. (1967) showed a significant relationship ($r = 0.59$) between PAW and spring wheat yield response to N fertilizer. In a summary of northern Great Plains research, Johnson (1964) cited correlation coefficients of 0.77 to 0.85 for sites in western North Dakota. Smith et al. (1978), Goyne et al. (1978), and Dubbelde et al. (1982) all emphasized the importance of PAW for sunflower production in Australia and Bauder and Ennen (1982) studied sunflower water use in North Dakota.

Lehane and Staple (1964) reported that one inch of PAW increased wheat yield in Saskatchewan by 1.8, 3.2, and 2.7 bushels per acre on sandy loam, loam, and clay soils, respectively. Johnson (1964) reported wheat yield increases of 2.0, 3.4, and 1.0 bushels per acre per inch of PAW at Dickinson, Mandan, and Williston, ND, respectively. Bauer (1972) reviewed the relationship between PAW and crop production in the northern Great Plains and reported an average wheat yield increase of 2.4 bushels per acre per inch of PAW. Yield increases averaged 2.5 bushels per acre per inch in North Dakota. He also reported that PAW was more important in western North Dakota than in the subhumid eastern portion of the state. In some instances PAW was negatively correlated with yield in eastern North Dakota, indicating an excess of water, particularly in the Red River Valley.

Several researchers have used PAW with rainfall probabilities and fertility levels to estimate wheat yield (Halverson and Kresge, 1972; Vasey and Leholm, 1982). However, many environmental factors such as insects, disease, drought, hail, wind, and nutrient deficiencies can affect final yield (Johnson, 1964). Eck and Stewart (1959) and Goos et al. (1984) found that low R^2 values and poor accuracy of predictive models are major drawbacks of seasonal yield estimation. Bauer (1972) stated that inaccuracies in laboratory procedures and the possibility that crops do not use all PAW are major concerns in relying on PAW to make yield predictions.

The purpose of this study was to quantify the influence of PAW on spring wheat (*Triticum aestivum* L.) and sunflower (*Helianthus annuus* L.) production for selected soil, climatic, and management conditions in North Dakota and to stress the importance and limitations of using PAW in making management decisions.

METHODS

Yield and soil data from replicated fertilizer rate experiments located throughout the state were used in these analyses. Data were separated into three sets: Wheat 1 consisted of data from 492 plot-years collected between 1977 and 1982; Wheat 2 was comprised of 1072 plot-years of data collected from 1958 to 1961; and Sunflower was represented by 233 plot-years of data collected from 1977 to 1982. To simulate actual field conditions, all plot treatments, including low-yielding and nonresponding treatments, were included in the analyses. Soil type, field procedure, plot descriptions, management practices, and data set stratifications for the Wheat 1 and Sunflower data sets are summarized by Ulmer (1986). Similar information for the Wheat 2 data set is available from Ozbun (1961) or Bauer et al. (1970).

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All data were obtained from on-site measurements or observations. Plant available water at seeding was determined by sampling to 48 and 60 inches on wheat and sunflower sites, respectively. Bulk density was determined by the core method (Blake, 1965). Water at 15 bar was determined by pressure plate apparatus (Richards, 1947). Statistics summarizing the data sets are shown in Table 1.

To isolate effects of PAW from the confounding influence of fertility, all data were partitioned by site nutrient level and corresponding yield, using fertilizer recommendations by Dahnke et al. (1981a, 1981b). Sites at which nutrients were adequate for the attained yield were partitioned into the Fertility Level A data set.

Regression and correlation techniques were used in all analyses. Results from subgroups with small sample sizes were not reported, explaining apparent missing results. All results reported were significant at the 10% probability level.

RESULTS AND DISCUSSION

Average wheat and sunflower yield increased with increasing PAW (Figure 1). Average PAW needed to obtain a yield of at least 20 bushels per acre, considered by Goos et al. (1984) as the break-even point between crop failure and success, was 4.2 inches for the Wheat 1 data set and 4.4 inches for the Wheat 2 data set. These figures are slightly higher than those cited by Goos et al. (1984), which were developed from an analysis of crop failure frequencies in northwestern North Dakota.

Sunflower response to PAW was generally similar to wheat. Assuming the break-even point for sunflower is 1200 pounds per acre, an average minimum of 5.3 inches of PAW (to a depth of 60 inches) is necessary to obtain this yield.

Plant available water at seeding explained between 27 and 41 percent of the total variation in yield for the various data sets (Figure 2). There was little difference in the influence PAW had on yield between the Overall and Fertility Level A subgroup in the Wheat 2 and the Sunflower data sets. However, in the Wheat 1 data set, PAW explained considerably more variation in the Fertility Level A subgroup (41 versus 31 percent), indicating that adequate fertility increases the influence PAW has on yield. Results are similar to those reported by Army and Hanson (1960) and Lehane and Staple (1964) from work in Montana and Saskatchewan, respectively, but lower than those from North Dakota reported by Johnson (1964). Plant available water

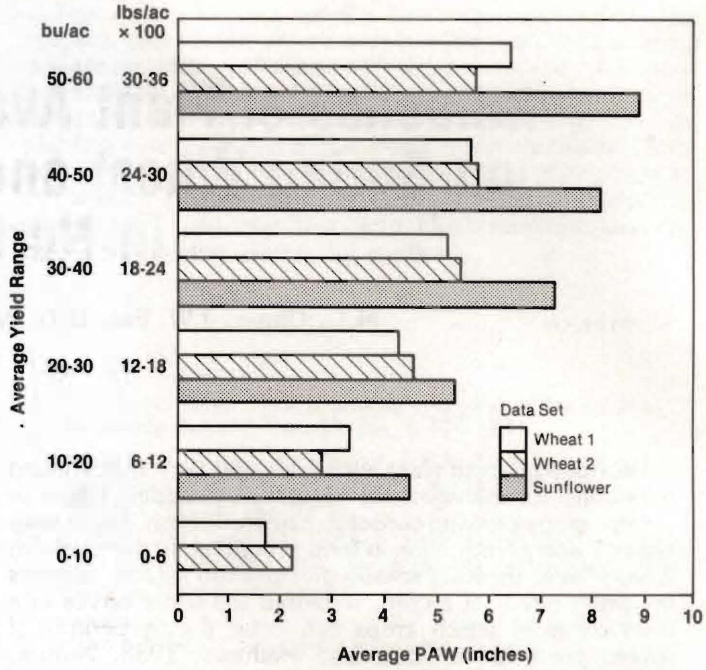

Figure 1. General relationship between yield and PAW.

at seeding contributed an average of 3.5 and 2.4 bushels per acre per inch for the Wheat 1 and 2 data sets, respectively (Figure 2). With adequate fertility (Fertility Level A of the Wheat 1 data set), each inch of PAW resulted in an average yield increase of 4.2 bushels per acre.

The Wheat 2 data set is 25 years old and the leveling off of yields at higher amounts of PAW probably reflects technological changes as described by Brun et al. (1984). They found technology increased yield potential per inch of evapotranspiration by about 50 percent from 1930 to 1980. Similarly, this analysis suggests the yield potential of an inch of PAW has increased 30 to 45 percent from 1960 to 1980.

Plant available water at seeding increased sunflower yield linearly by an average of 111 and 110 pounds per acre per inch in the Overall and Fertility Level A sunflower data sets, respectively (Figure 2).

Table 1. Summary of yield and PAW for various data sets.

	Yield[a]			PAW[b]		
Data set	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**
Wheat 1	28.2	12.6	1.9 - 64.0	4.6	2.4	0.2 - 15.5
Wheat 2	26.6	12.0	3.9 - 63.9	4.1	2.5	0.2 - 11.6
Sunflower	1839.7	456.3	700.0 - 3092.0	6.6	2.4	2.0 - 11.1

[a]Yields for Wheat 1 and Wheat 2 in bu/a, Sunflower yield in lb/a.
[b]PAW in inches was measured to 48 inches for the Wheat 1 and Wheat 2 data sets and to 60 inches for the Sunflower data set.

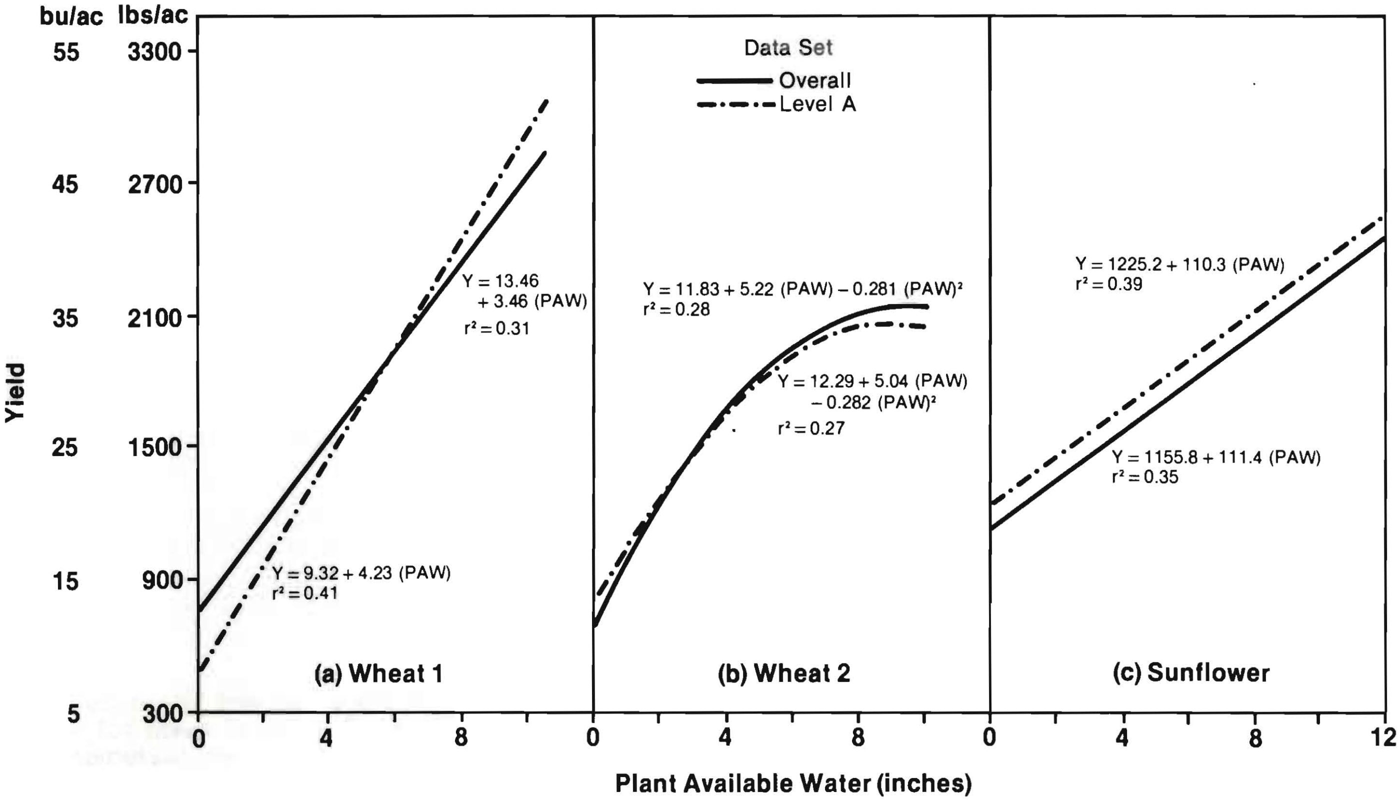

Figure 2. Effect of PAW on wheat and sunflower yield.

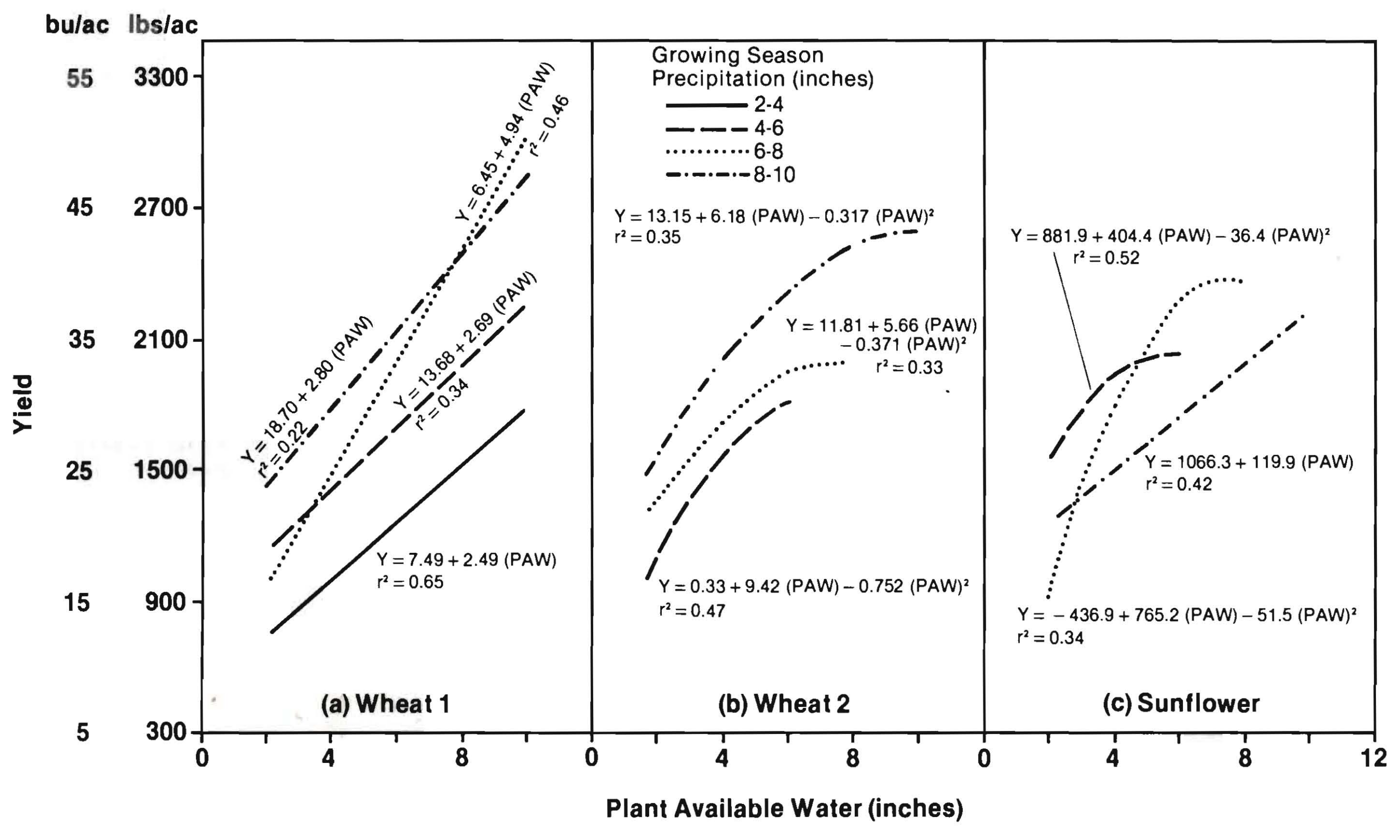

Figure 3. Effect of PAW on yield under variable growing season precipitation conditions.

The amount of yield variation explained by PAW varied with climatic, soil, and management factors. Generally, as growing season precipitation increased, the amount of yield variability explained by PAW decreased (Figure 3). Results indicate that a reservoir of available water was more important to production during drier seasons, supporting Bauer's (1972) findings that PAW was more important in western than in eastern North Dakota.

Soil drainage class (Soil Survey Staff, 1951) also affected the importance of PAW in wheat and sunflower production (Figure 4). Plant available water explained 3 to 6 times more yield variation for Borolls (moderately well or well drained soils) than on Calciaquolls (somewhat poorly or poorly drained soils). Calciaquolls have a seasonal water table which mitigates the importance of PAW. Bauer (1972) reported a small negative correlation between yield and PAW on the predominately poorly drained soils of the Red River Valley.

Yield increase due to PAW was affected by soil drainage class. In Calciaquolls, PAW contributed only 25, 44, and 45 percent of the yield increase attributed to PAW in Borolls in the Wheat 2, Sunflower, and Wheat 1 data sets, respectively (Figure 4a, b, c). Although the initial yield of Calciaquolls was higher, in all cases the yield of Borolls surpassed Calciaquolls when adequate PAW was available. These data emphasize the importance of maximizing infiltration and conserving soil water on most North Dakota soils.

Soil texture influenced the effect PAW had on yields in the Wheat 1 data set (Figure 5). Plant available water was more important in explaining yield variation on fine-loamy and coarse-loamy soils than on fine textured soils. Although fine and fine-loamy soils have a greater initial yield, with adequate PAW, yields on coarse-loamy soils can equal those of soils with greater water-holding capacity. These results indicate that producers with coarse-loamy soils need to be especially aware of their moisture conservation program. There was inadequate textural variation in the Wheat 2 and sunflower data sets to allow for investigation.

An interaction between soil fertility and PAW is evident from these data. Generally as PAW increased, nitrogen levels (soil NO_3-N plus fertilizer N) explained more of the variability in yield (Figure 6). Similarly, as N levels increased, PAW tended to explain more yield variability (Figure 7). As N levels increased, PAW was used more efficiently by both crops. The importance of maximizing PAW in an effective fertility program is clear. This PAW-fertility interaction has also been described by Norum (1963) and Young et al. (1967).

CONCLUSIONS

Data presented in this article and results from other research show that 3 to 4 inches of stored soil water at seeding is essential for successful crop production in the

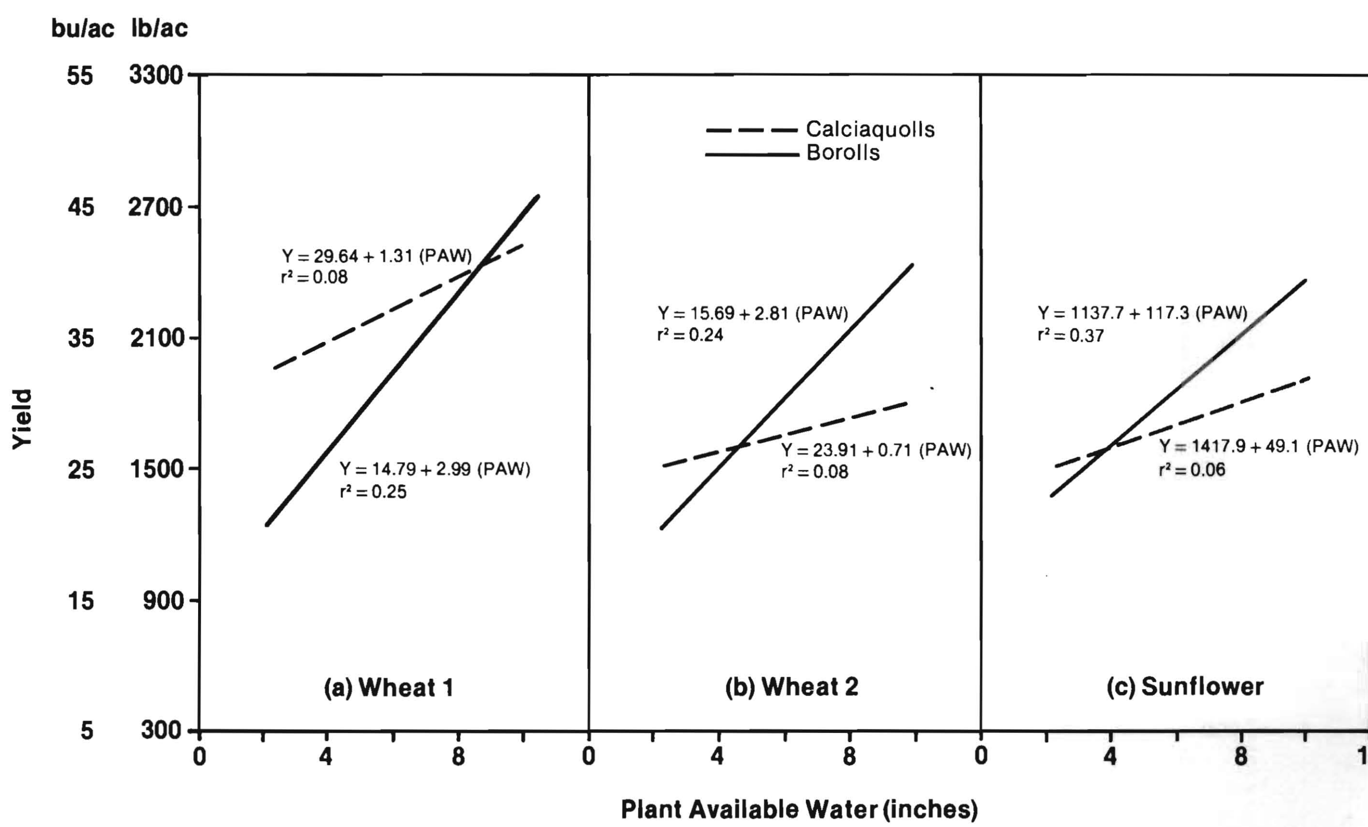

Figure 4. Effect of PAW on yield under variable soil drainage conditions.

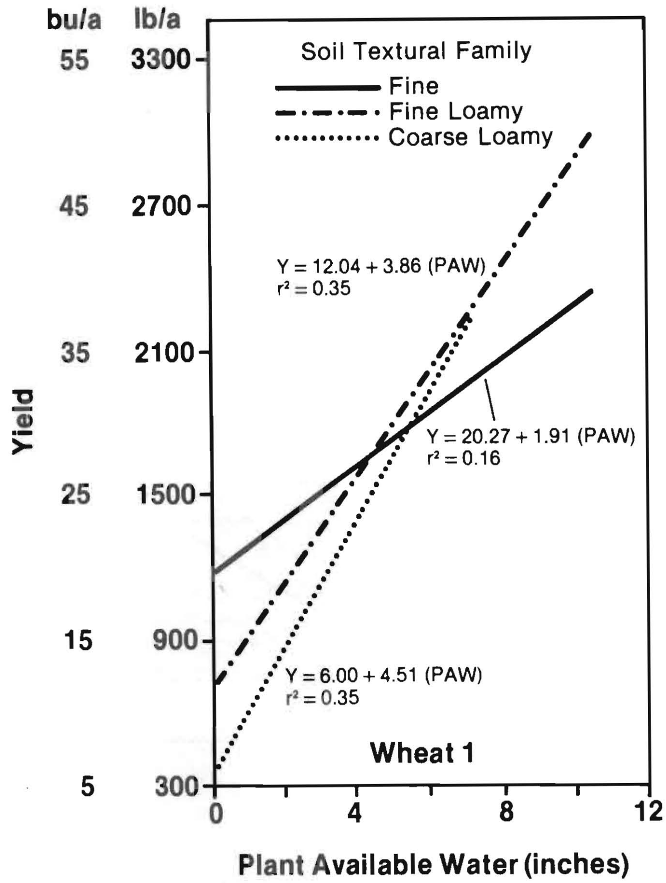

Figure 5. Effect of PAW on yield under variable soil textural conditions for the Wheat 1 data set.

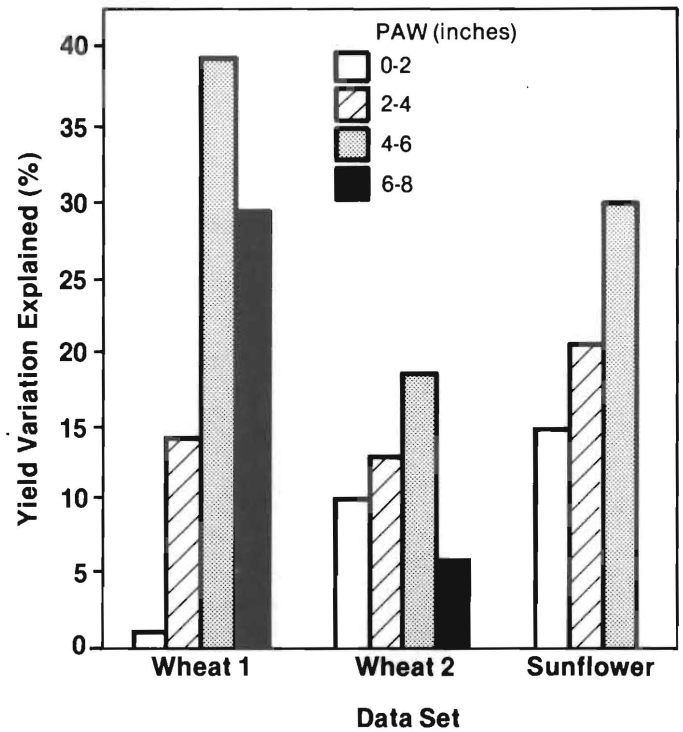

Figure 6. Percent variation in yield explained by soil NO_3-N (to 24 inches) plus fertilizer N under variable PAW conditions.

northern Great Plains. Plant available water at seeding is especially important during dry seasons and on well-drained soils. The fertility-PAW interaction also needs special consideration to make optimum use of both resources. For example, if a manager could conserve an additional 2 inches of PAW on a medium textured soil given average fertility, wheat yields would increase an average of 7 bushels per acre; however, under higher fertility conditions yield increases would be expected to average 8.4 bushels per acre. Under adequate fertility an average increase in sunflower yield of 220 pounds per acre could be expected from 2 additional inches of PAW.

Results of this study emphasize the value of an active soil water management and conservation program. Residue management, proper and timely tillage, crop rotations, and a thorough knowledge of soil-water relationships are part of a comprehensive management system that minimizes soil erosion and the occurrence of saline seeps while enhancing wheat and sunflower production. Farm operators should assess their management practices in order to make optimum use of available water by conserving fall and winter precipitation.

Results support the FLEXCROP management system concept which bases cropping decisions on the quantity of stored soil water. Problems can occur, however, when PAW is the only variable considered in making fertilizer recommendations. In addition to PAW, variations in yield are determined by soil and climatic conditions and management practices. Seasonal yield prediction models that rely only on PAW and rainfall probabilities for input must be used cautiously. They should be thoroughly tested under a wide range of climatic and soil conditions to assess their usefulness.

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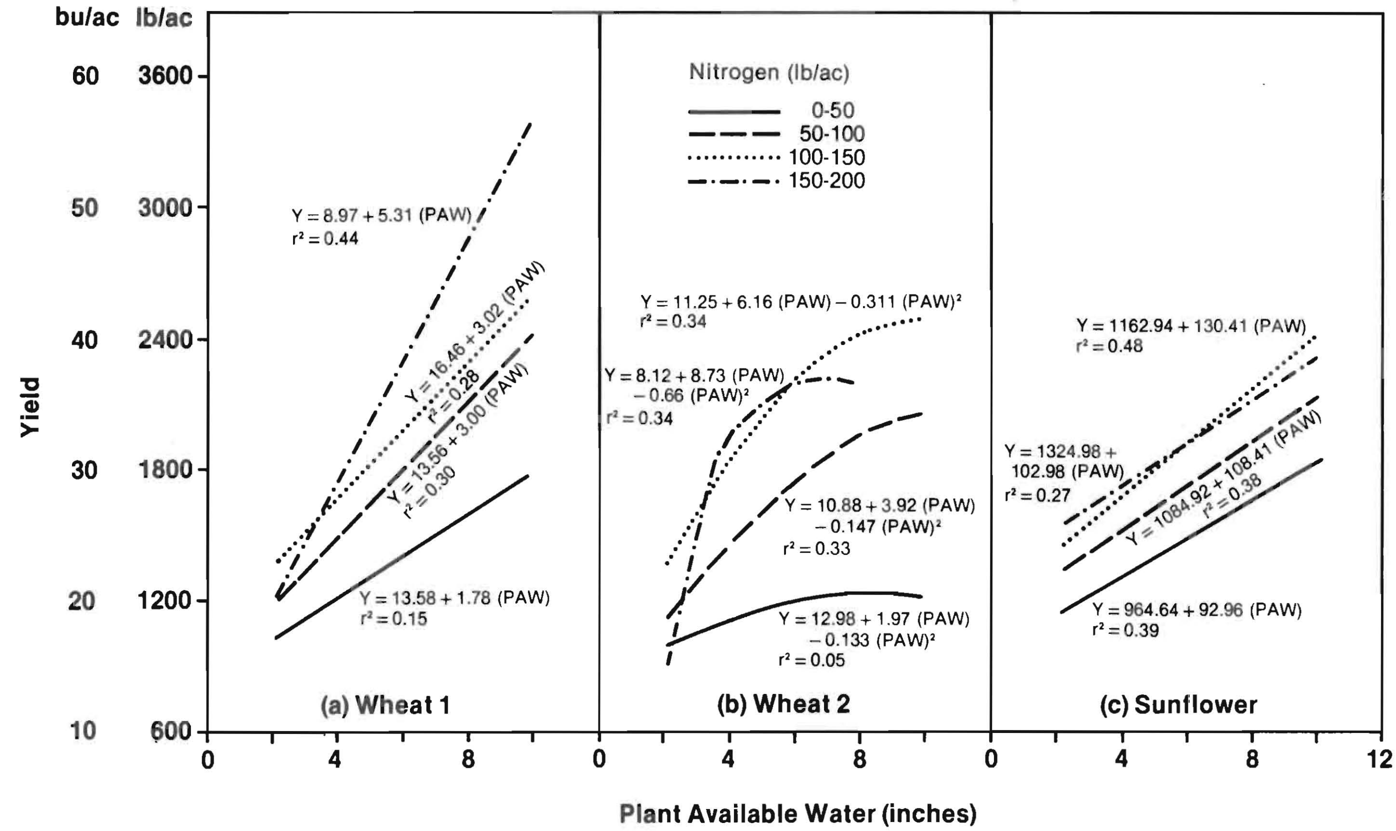

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presence each year in the crop production system may be anticipated. But plant diseases are constantly changing like the diseases of animals and man. It should not be surprising, then, to discover that two species of Septoria, previously either not found in North Dakota or found at noneconomic levels, should suddenly appear on our wheat crop under unusual environments.

Diseases on North Dakota crops have appeared and disappeared before. White rust and downy mildew attacked mustard in the Langdon area in the early 1960s and then became scarce. Septoria blotch has waxed and waned on North Dakota barley. While the immediate within-year losses to these diseases were serious, the problem was to determine if they were a continuing economic problem. This could only be answered by field, greenhouse and laboratory studies over time.

No control program was initiated for aster yellows on flax although it caused serious losses in the late 1950s and later ceased to be an economically important factor. However, growers who have had losses to diseases that came and disappeared after a few seasons are understandably demanding that the problem be solved. Solutions to such problems may not be quickly forthcoming, because practical and economic control are not always possible. If the problem is not a lasting one (e.g. aster yellows on flax), reduced budgets and higher priority problems will prevent resources from being assigned to this new problem. Even with good sources of major gene resistance, developing varieties with these additional resistance genes plus good agronomic characteristics takes several years and the fiscal resources that are currently being used on other problems. If the genes for resistance are polygenic, the development of resistant varieties will take longer and be more expensive.

The contest between man with his desired crop varieties and the world of pathogens is an ageless and continuing one that requires continued inputs of money and personnel. These economic inputs are required of public and private crop improvement programs. New technologies offer additional methods of achieving improved crop varieties, but they will not terminate the contest between man's crops and crop diseases.

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extent that cooperatives have a low-cost structure and are free to engage in differential pricing, they are in a relatively favorable position.

Availability of Cost Data

One of the most disappointing and yet not surprising findings was the lack of cost data on which to base differential pricing decisions. Several elevators had detailed cost information but did not have it classified in a way that differential pricing policies could be defended. If accurate cost data is not available, differential prices may not include equal margins. Members have a right to know that one group of patrons is not subsidizing another.

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